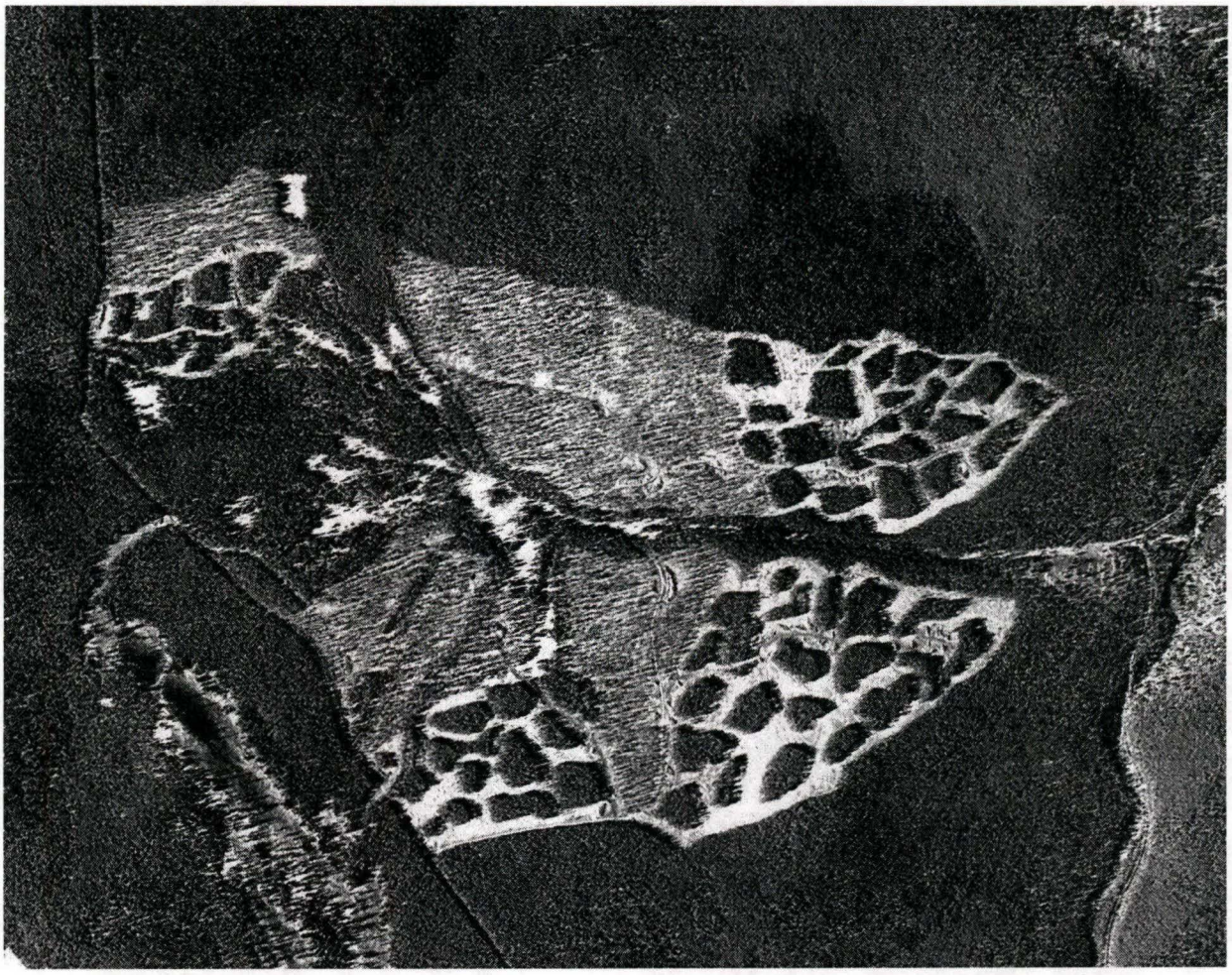
Thesis/
Reports
Farnes,
P. E.

EVALUATION OF CLIMATIC DATA, POST-TREATMENT WATER YIELD AND SNOWPACK DIFFERENCES BETWEEN CLOSED AND OPEN STANDS OF LODGEPOLE PINE ON TENDERFOOT CREEK EXPERIMENTAL FOREST

Agreement no:
01-JV - 11222022-115

EVALUATION OF CLIMATIC DATA, POST-TREATMENT WATER YIELD AND SNOWPACK DIFFERENCES BETWEEN CLOSED AND OPEN STANDS OF LODGEPOLE PINE ON TENDERFOOT CREEK EXPERIMENTAL FOREST

FINAL REPORT



Phillip Farnes and Katherine Hansen
Department of Earth Sciences
Montana State University
Bozeman, Montana, 59717
and
Ward McCaughey
USDA Forest Service
800 East Beckwith, P. O. Box 8089
Missoula, Montana 59807

June 2002

EVALUATION OF CLIMATIC DATA, POST-TREATMENT WATER YIELD AND SNOWPACK DIFFERENCES BETWEEN CLOSED AND OPEN STANDS OF LODGEPOLE PINE ON TENDERFOOT CREEK EXPERIMENTAL FOREST

FINAL REPORT

MSU Grants and Contract No. 426004
USFS Joint Venture Agreement No. 01-JV-11222022-115

To

Ward McCaughey
Forest Service Technical Representative
U. S. Department of Agriculture, Forest Service
Rocky Mountain Research Station
Research Work Unit 4151
800 East Beckwith, P. O. Box 8089
Missoula, Montana 59807

Report Prepared by
Phillip Farnes[1] and Katherine Hansen[2]
Department of Earth Sciences
Montana State University
Bozeman, MT 59717

June 2002

[1]Research Scientist and [2]Professsor and Principal Investigator,
Department of Earth Sciences, MSU

ACKNOWLEDGEMENT

We appreciate the contributions of the following people and agencies that helped make this report possible. Ward McCaughey, his staff and cooperators collected much of the basic data from Tenderfoot Creek Experimental Forest. The Natural Resources and Conservation Service has collected and archived data from SNOTEL sites and snow courses and collected more recent data from Sheep Creek stream gaging station. Earlier record of Sheep Creek runoff was collected and archived by the U. S. Geological Survey. The National Weather Service and their observers have collected and archived climatological data from stations near the Experimental Forest. Mrs. Florence Wisdom has continued to collect precipitation data at the White Sulphur Springs 10N location and has graciously provided previously unpublished data to the authors. The Department of Earth Sciences at Montana State University has provided administrative support. The Forestry Sciences Laboratory, U. S. Forest Service, Bozeman, Montana, provided funding for this project, office space and technical support.

TABLE OF CONTENTS Page

ACKNOWLEDGMENTS 1

TABLE OF CONTENTS 2

LIST OF FIGURES AND TABLES 3

INTRODUCTION 4

INPUT INTO COMPUTER FILES ALL SNOW AND RELATED DATA 4

AVERAGE ANNUAL PRECIPITATION MAP 6

DEVELOP RELATIONSHIP BETWEEN SWE MEASURED AT THE ONION PARK OPEN AND CANOPY PILLOWS. 8

ESTIMATE WATER-YIELD CHANGES EXPECTED FROM CUTTING TREATMENTS ON TWO WATERSHEDS ON TCEF 9

REFERENCES 12

APPENDIX 1. AVERAGES OF ALL SNOW AND PRECIPITATION STATIONS ON TENDERFOOT CREEK EXPERIMENTAL FOREST FOR1971-2000 BASE PERIOD 13

APPENDIX 2. FIRST AND MIN-MONTH SNOW WATER EQUIVALENT FOR SNOW PILLOWS ON TENDERFOOT CREEK EXPERIMENTAL FOREST FOR PERIOD OF RECORD 14

APPENDIX 3. ESTIMATED MONTHLY SNOW WATER EQUIVALENT FOR OPEN SNOW COURSES ON TENDERFOOT CREEK EXPERIMENTAL FOREST FOR PERIOD OF RECORD 17

APPENDIX 4. ESTIMATED MONTHLY PRECIPITATION OR PERIOD OF RECORD FOR PRECIPITATION GAGES ON TENDERFOOT CREEK EXPERIMENTAL FOREST 25

APPENDIX 5. MONTHLY PRECIPITATION AVERAGES FOR STATIONS ON AND NEAR TENDERFOOT CREEK EXPERIMENTAL FOREST FOR 1971-2000 BASE PERIOD USED IN FIGURE 3 39

APPENDIX 6. TECHNICAL PAPER ON SNOWPACK COMPARISONS BETWEEN AN OPENING AND A LODGEPOLE STAND PRESENTED AT WESTERN SNOW CONFERENCE IN APRIL 2001 40

LIST OF FIGURES AND TABLES

Page

Figure 1. Drainages, sub-drainages and data sites on Tenderfoot Creek Experimental Forest. 6

Figure 2. Average annual precipitation map for 1971-2000 for Tenderfoot Creek Experimental Forest drawn by Farnes. 9

Figure 3. Distribution of 1971-2000 average annual precipitation by months for stations in and near Tenderfoot Creek Experimental Forest. 11

Figure 4. Double-mass curves for pre-treatment years for control and treated watersheds in Tenderfoot Creek Experimental Forest. 12

Table 1. Area by average annual precipitation for pre- and post-treatment cover types for Sun Creek and Spring Park Creek drainages. 11

INTRODUCTION

This cooperative joint venture agreement between Montana State University and U. F. Forest Service has four objectives.

A. Input into computer files, all snow and related climate data from Tenderfoot Creek Experimental Forest.

B. Produce an updated 30-year average annual precipitation map based on the 1971-2000 period.

C. Summarize, analyze, and publish a report/manuscript on comparison of snowpack between open and closed canopy stands of lodgepole pine.

D. Estimate change in water yield due to research silvicultural cutting treatments.

Data collection on Tenderfoot Creek Experimental Forest was initiated in 1992 and has expanded to the present time. A preliminary report was prepared to include data collection through the 1995 season (Farnes et al, 1995). Some data was updated in Farnes et al, 1999. Since then, data has been collected but has not been edited, summarized or tabulated in electronic form. This Joint Venture Agreement (JVA) was initiated to summarize all climatic and water yield data collected since 1992 and make it available electronically. The standard 30-year base period was recently updated from 1961-1990 to 1971-2000. New averages and precipitation map were to be developed.

INPUT INTO COMPUTER FILES ALL SNOW AND RELATED CLIMATIC DATA

Data at Tenderfoot Creek Experimental Forest (TCEF) has been collected by electronic data recorders, manual measurements and analog data recorders. Figure 1 shows the Tenderfoot Creek Experimental Forest, sub-drainages and location of data sites. Since the inception of data collection, there has been a progression from manual and analog data to electronic data. It was necessary to prepare and edit historic data so that it would be compatible with data that is currently being collected. Data includes snow water equivalent (SWE) measured manually at snow courses and measured and recorded daily using snow pillows; precipitation measured manually in storage gages and measured daily using electronic recorders; and daily maximum, minimum and average temperatures measured electronically. Missing data was estimated using correlations between sites within TCEF and SNOTEL sites at Spur Park and Deadman Creek. These sites were also used to validate data collected on TCEF. There was a Remote Area Weather Station (RAWS) at Onion Park from July 3, 1996 through July 2, 2001 identified as Tenderfoot in the RAWS database. Air temperature and precipitation during non-freezing periods from this station were used to estimate some of the missing data. Electronic copies of the final completed dataset were provided to the Forest Service representative for inclusion into the TCEF database.

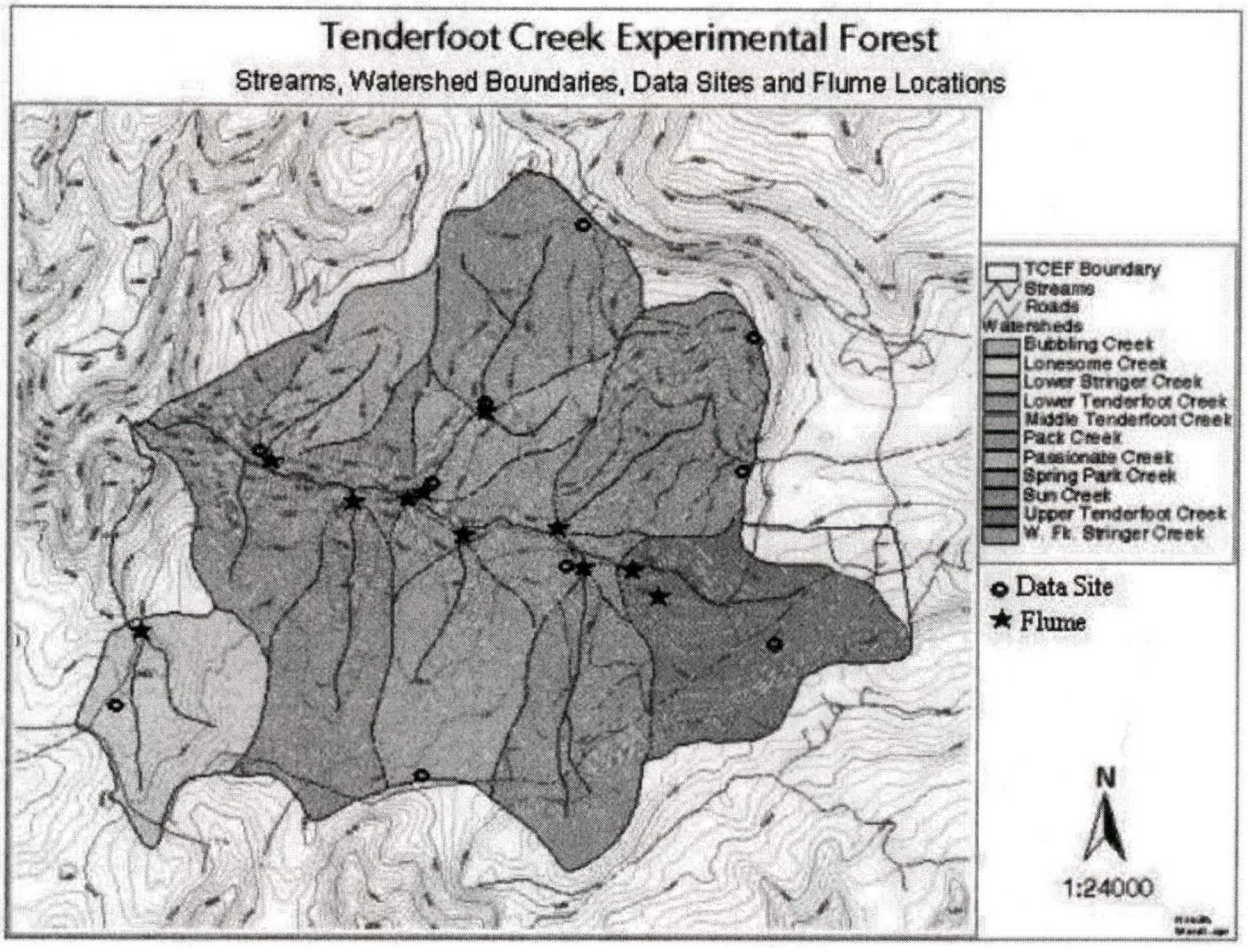


Figure 1. Drainages, sub-drainages and data sites on Tenderfoot Creek Experimental Forest.

The Natural Resources and Conservation Service (NRCS) and U. F. Forest Service installed SNOTEL equipment at Onion Park and Stringer Creek data sites in fall of 2001. Daily data collected prior to this time was tabulated, edited and formatted to be compatible with the data currently being collected by SNOTEL. This includes SWE, total precipitation and air temperature data. This historic data was provided to the Forest Service representative and to Natural Resources and Conservation Service to enter into their SNOTEL database.

Appendix 1 shows 1971-2000 averages of SWE and precipitation.

Monthly SWE and precipitation data for the manual sites for period of record was calculated and edited. Electronic copy of this data was provided to Forest Service representative for inclusion into the TCEF database and is shown in Appendices 2, 3, and 4.

Monthly and annual precipitation averages for 1971-2000 for climatological stations near Tenderfoot Creek Experimental Forest are presented in Appendix 5.

AVERAGE ANNUAL PRECIPITATION MAP

Since the 1961-1990 base period was updated to 1971-2000 in 2002, and since additional data has been collected since the 1961-1990 averages were calculated, it was decided to update the average annual precipitation map to 1971-2000 on the 1:24,000 scale. New averages were calculated for all precipitation stations in and adjacent to the Experimental Forest (Appendices 1 & 5). An elevation vs. average annual precipitation curve was used to obtain elevations where equal increments of precipitation would occur throughout the Experimental Forest. Isohyetal lines were then drawn between measured locations (Farnes, 1971). The overlay of isohyetal lines for TCEF was provided to the Forest Service representative for entering into the TCEF Geographic Information System (GIS) database.

A reduced copy of the 1971-2000 average annual precipitation map drawn by Farnes is shown in Figure 2. The average annual precipitation maps currently being developed using GIS systems have been found to be unreliable for smaller scales needed for operational uses.

The monthly distribution of average precipitation for stations in and near TCEF is shown in Figure 3. The difference between valley and mountain locations should be noted. Winters are good precipitation producers in higher elevations but valleys have low precipitation. Springs are wet in the valleys compared to winter months. In the mountains, spring months produce precipitation comparable to winter months.

Figure 2. Average annual precipitation map for 1971-2000 for Tenderfoot Creek Experimental Forest drawn by Farnes.

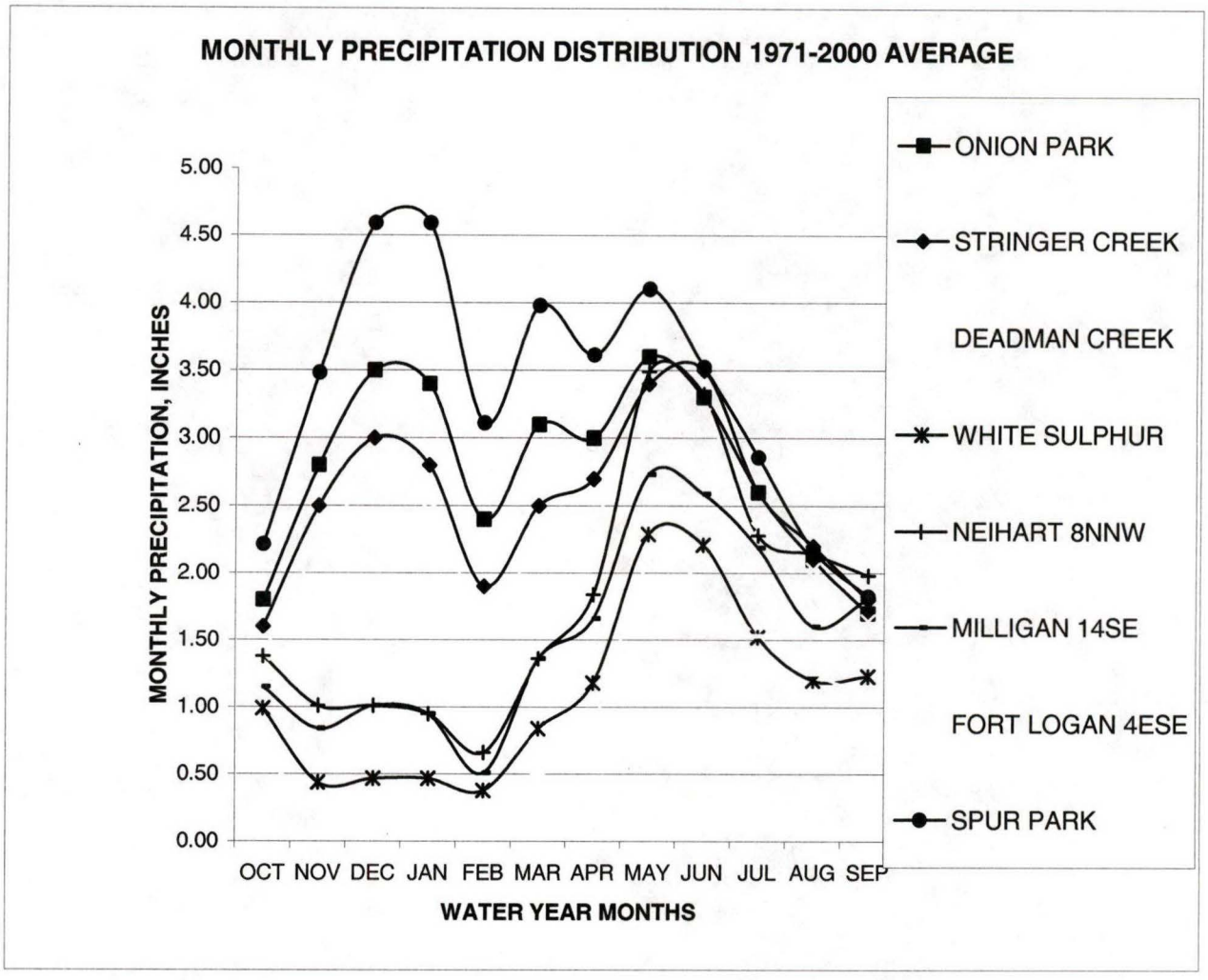


Figure 3. Distribution of 1971-2000 average annual precipitation by months for stations in and near Tenderfoot Creek Experimental Forest.

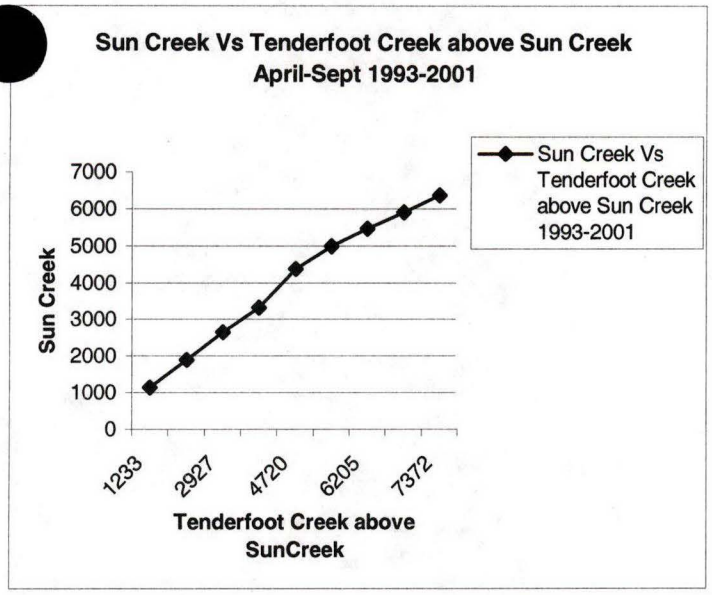
DEVELOP RELATIONSHIP BETWEEN SWE MEASURED AT THE ONION PARK OPEN AND CANOPY PILLOWS

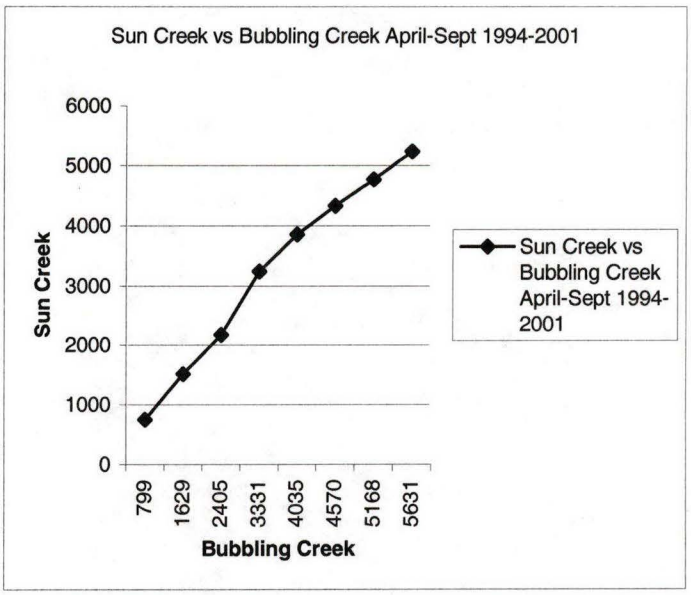
Two snow pillows were installed at Onion Park in the fall of 1993. One was in the open comparable to an NRCS installation. The other snow pillow was installed under the forest canopy. SWE was recorded daily. Results of seven years of data was reported in a technical paper published in the proceedings of the 69th annual meeting of the Western Snow Conference at Sun Valley, Idaho, April 17-19, 2001. The annual maximum SWE on the canopy pillow averaged 77 percent of the open pillow. Melt rates under the canopy averaged 46 percent of that in the open. Snow under the canopy melted out 9 days after the open pillow melted out. A copy of this publication is presented in Appendix 6.

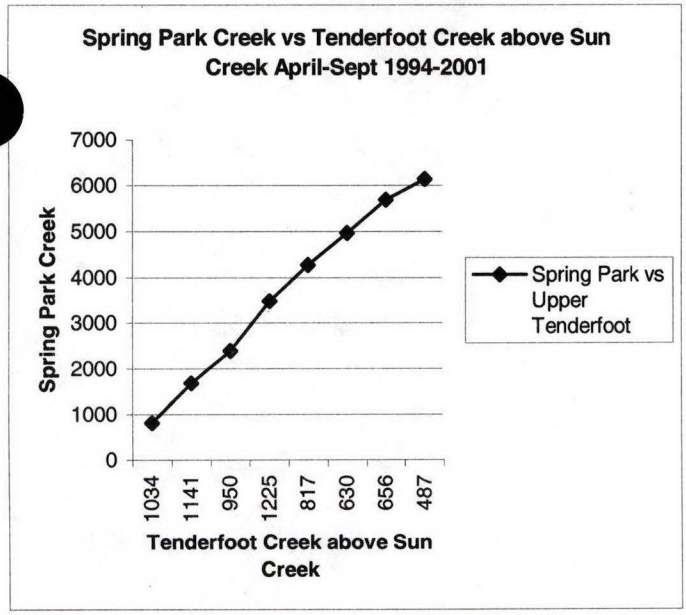
ESTIMATE WATER-YIELD CHANGES EXPECTED FROM CUTTING TREATMENTS ON TWO WATERSHEDS ON TCEF

Cutting and burning treatments were imposed on the Sun Creek and Spring Park Creek watersheds in 2001and 2002. Removal of forest canopy increases snow being deposited on the ground and increases the amount of rain reaching the soil surface. (Farnes et al, 2002) This increases the subsequent runoff volume and may change the timing of the peak runoff. The amount of increase depends on volume of forest canopy removed and precipitation zone of the removal. Using the relationship between average annual precipitation and April 1 SWE (April 1 SWE = 0.724 X Annual Precipitation – 8.4; $R^2 = 0.984$), it is possible to estimate the increase in snowpack in the removal areas. The relationship between the average annual precipitation and April through July precipitation (April-July Precipitation = 0.247 X Annual Precipitation + 4.3; $R^2 = 0.976$) is used to estimate increase in throughfall of precipitation. The yield vs. average annual precipitation curve provides the percentage of the annual precipitation that becomes runoff. Using the curve developed in Farnes et al 2002 for the precipitation range across TCEF, the percentage of annual precipitation that becomes runoff was estimated as 1.329 X Annual Precipitation + 0.8. By comparing pre-treatment estimated yield with estimated post-treatment yield, it is possible to estimate the increase that will occur as a result of canopy removal. From studies on TCEF and other areas, the April 1 snowpack under the forest canopy is about 75 percent of the open and throughfall of April –July precipitation under the forest canopy is about 73 percent of that which falls in the open. The removals were targeted for specific volumes but subsequent blowdown, and actual burn intensities for treatments in 2002 may alter the actual removal. These values will be determined in future years. For this study, we used approximate programmed removals. The pre- and post-treatment yield for Sun Creek and Spring Park Creek is shown in Table 1. It is estimated that the increase in annual yield will be_____ percent in Sun Creek an_____ percent in Spring Park Creek. Future monitoring of streamflow in these and adjacent watersheds and comparison by double-mass analysis between treatment and control watersheds for pre- and post treatment years will be used to check accuracy of these estimates. Double-mass analysis for pre-treatment years is shown in Figure 4. Some variation from a straight line is noted for earlier years on Sun Creek and could be related to work done with a backhoe to enlarge the stilling basin above the Sun Creek flume.

Table 1. Areas by average annual precipitation for pre- and post- treatment cover types for Sun Creek and Spring Park Creek drainages.







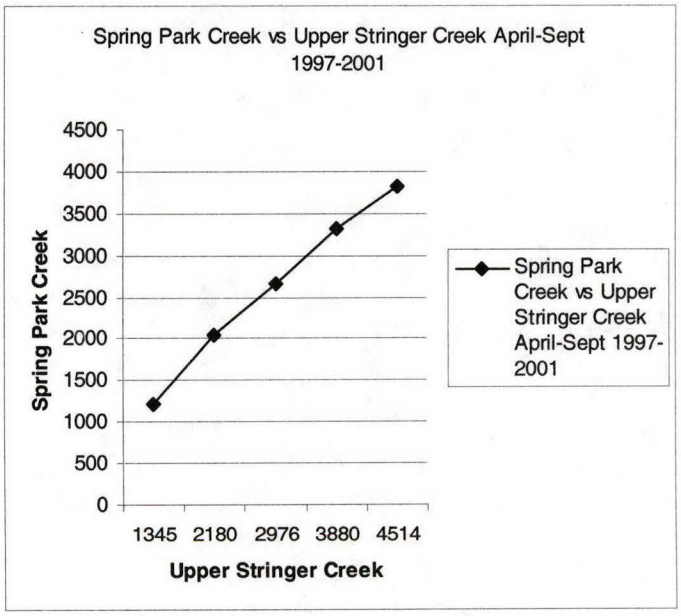


Figure 4. Double-mass curves for pre-treatment years for control and treated watersheds in Tenderfoot Creek Experimental Forest.

REFERENCES

Farnes, P. E. 1971. Mountain precipitation and hydrology from snow survey. Proceedings: Western Snow Conference; April 20-22; Billings, MT: 44-49.

Farnes, P. E., W. W. McCaughey, and K. J. Hansen. 1995. Hydrologic and Geologic Characterization of Tenderfoot Creek Experimental Forest, Montana. Final Report RJVA-INT-92734. Department of Earth Sciences, Montana State University, Bozeman, MT 63p.

Farnes, P. E., W. W. McCaughey, and K. J. Hansen. 1999. Flumes, Historic Water Yield and Climatological Data for Tenderfoot Creek Experimental Forest, Montana; Final Report RJVA-INT-96071. Department of Earth Sciences, Montana State University, Bozeman, MT. 37p.

Farnes, P. E., W. W. McCaughey, and K. J. Hansen. 2002. Role of Fire in Determining Annual Water Yield in Mountain Watersheds. In: Chapter 10, After the Fire: Ecology of Change in Yellowstone National Park. Edited by Linda Wallace, Yale University Press. (In Press)

Appendix 1. Averages for all snow and precipitation stations on Tenderfoot Creek Experimental Forest for 1971-2000 base period.

TENDERFOOT CREEK EXPERIMENTAL FOREST

1971-2000 AVERAGES

SNOW PILLOWS SWE in inches

SITE NAME	OCT 1	OCT 15	NOV 1	NOV 15	DEC 1	DEC 15	JAN 1	JAN 15	FEB 1	FEB 15	MAR 1	MAR 15
ONION PARK OPEN PILLOW	0.0	0.3	0.9	1.6	3.4	4.2	6.3	7.6	8.6	9.4	10.2	11.1
ONION PARK CANOPY PILLOW	0.0	0.2	0.6	1.1	2.3	2.9	4.4	5.4	6.2	6.8	7.3	8.0
STRINGER CREEK PILLOW	0.0	0.1	0.4	1.1	2.6	3.4	5.1	6.4	7.4	8.1	8.7	9.8

	APR 1	APR 15	MAY 1	MAY 15	JUN 1	JUN 15	DATE SNOW STARTS	MAX SWE	DATE MAX SWE	DATE SNOW ZERO	SNOW COVER DAYS	SNOW FREE DAYS
ONION PARK OPEN PILLOW	13.0	14.6	13.7	10.3	3.6	0.0	10/14	14.8	5/1	6/4	229	136
ONION PARK CANOPY PILLOW	9.7	11.0	10.8	9.9	6.0	0.9	10/19	11.9	5/7	6/13	235	130
STRINGER CREEK PILLOW	11.0	11.8	8.0	3.7	0.7	0.0	10/26	11.8	4/22	5/21	205	160

SNOW COURSES SWE in inches

SITE NAME	OCT 1	NOV 1	DEC 1	JAN 1	FEB 1	MAR 1	APR 1	MAY 1	MAY 15	JUN 1	DATE SNOW ZERO
BUBBLING SPRINGS	0.0	1.0	4.2	7.8	10.4	12.2	15.3	16.0	12.4	5.2	6/4
COUNTY LINE	0.0	1.3	4.8	8.6	11.7	13.9	17.1	18.9	16.0	8.2	6/9
DRY PARK	0.0	1.1	4.2	7.7	10.4	12.2	15.1	15.8	12.1	4.3	6/2
FARNES MEADOW	0.0	1.1	4.4	8.1	11.0	13.1	16.5	17.7	13.9	6.0	6/5
LONESOME CREEK	0.0	0.7	3.4	6.5	8.9	10.6	13.4	12.1	7.3	1.5	5/27
ONION PARK	0.0	1.0	4.2	7.9	10.7	12.6	15.8	16.5	12.7	4.7	6/1
STRINGER CREEK	0.0	0.4	2.8	5.5	7.8	9.0	11.0	8.9	4.1	0.3	5/19
SUN CREEK	0.0	0.7	3.9	7.2	10.3	12.0	14.9	14.1	9.1	2.5	5/28

PRECIPITATION GAGMonthly totals in inches

SITE NAME	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
BUBBLING SPRINGS	1.8	2.7	3.4	3.3	2.3	3.0	2.9	3.5	3.2	2.5	2.0	1.7	32.3
COUNTY LINE	1.9	2.8	3.7	3.6	2.5	3.3	3.1	3.6	3.2	2.5	2.0	1.6	33.8
DRY PARK	1.8	2.7	3.4	3.3	2.3	3.0	2.9	3.5	3.2	2.5	2.0	1.7	32.3
FARNES MEADOW	1.8	2.8	3.5	3.5	2.4	3.1	3.0	3.6	3.4	2.6	2.1	1.7	33.5
LONESOME CREEK	1.6	2.5	3.1	3.0	2.0	2.6	2.7	3.4	3.3	2.4	2.0	1.7	30.3
ONION PARK	1.8	2.8	3.5	3.4	2.4	3.1	3.0	3.6	3.3	2.6	2.1	1.7	33.3
PASSIONATE CREEK	1.3	2.0	2.3	2.2	1.5	2.0	2.3	3.2	3.3	2.4	2.0	1.7	26.2
STRINGER CREEK	1.6	2.5	3.0	2.8	1.9	2.5	2.7	3.4	3.5	2.6	2.2	1.8	30.5
SUN CREEK	1.7	2.6	3.2	3.1	2.1	2.7	2.8	3.4	3.4	2.5	2.1	1.7	31.3
UPPER STRINGER	1.6	2.5	3.1	3.1	2.1	2.7	2.8	3.5	3.5	2.6	2.2	1.8	31.5

Appendix 2. First and mid-month snow water equivalent for snow pillows on Tenderfoot Creek Experimental Forest for period of record.

Tenderfoot Creek Experimental Forest

ONION PARK OPEN PILLOW (Midnight of previous day) SWE in inches

WATER YEAR	OCT 1	OCT 15	NOV 1	NOV 15	DEC 1	DEC 15	JAN 1	JAN 15	FEB 1	FEB 15	MAR 1	MAR 15	APR 1	APR 15	MAY 1	MAY 15	JUN 1	JUN 15	JUL 1	DATE SNOW STARTS	MAX SWE	DATE MAX SWE	DATE SNOW ZERO	Snow Covered Days	Snow Free Days
1994	0.0	0.0	0.9	2.6	3.5	4.1	7.0	9.0	11.1	11.3	12.3	12.8	14.3	15.1	13.1	4.3	0.0	0.0	0.0	10/19	15.9	4/16	5/24	218	143
1995	0.0	0.0	1.4	2.4	3.9	4.3	5.9	7.0	8.2	9.1	8.9	9.6	13.7	16.1	17.5	18.0	9.6	0.2	0.0	10/15	18.0	5/14	6/15	244	129
1996	0.0	0.2	0.9	1.6	3.4	4.0	4.5	6.1	7.1	7.7	9.3	10.3	13.6	13.1	14.7	13.3	8.0	0.0	0.0	10/23	15.7	5/11	6/7	229	123
1997	0.0	0.1	1.5	1.9	4.3	4.9	9.5	10.8	11.8	13.0	14.5	15.7	16.6	19.1	18.4	15.9	4.7	0.0	0.0	10/9	19.1	5/8	6/4	239	126
1998	0.0	0.9	1.3	1.6	2.6	2.9	3.8	4.9	6.6	6.8	7.3	8.5	9.6	11.7	9.6	2.8	0.0	0.0	0.0	10/9	12.5	4/23	5/24	228	156
1999	0.0	0.0	0.1	1.2	3.4	4.8	6.3	8.2	9.3	10.1	11.2	11.3	11.3	12.3	11.2	11.3	1.2	0.0	0.0	10/28	13.0	4/19	6/3	219	133
2000	0.0	0.0	0.1	0.1	2.2	3.5	6.9	7.6	8.6	9.5	10.0	11.2	13.3	14.5	11.6	9.2	0.0	0.0	0.0	10/15	14.7	4/7	5/27	226	155
2001	0.0	0.7	0.2	1.0	2.2	2.4	4.2	4.5	5.5	6.3	6.9	8.1	9.3	11.1	9.2	2.6	0.0	0.0	0.0	10/30	11.2	4/23	5/19	202	144
2002	0.0	0.4	1.5	1.7	2.7	3.5	3.7	5.5	6.5	7.6	8.9	10.1	11.7	11.5	13.0	12.6	2.9	0.0	0.0	10/12	13.8	5/11	6/6	236	
2003																									
2004																									
2005																									
AVG 1971-2000	0.0	0.3	0.9	1.6	3.4	4.2	6.3	7.6	8.6	9.4	10.2	11.1	13.0	14.6	13.7	10.3	3.6	0.0	0.0	10/14	14.8	5/1	6/4	229	136

Appendix 2. (Continued)

Tenderfoot Creek Experimental Forest

ONION PARK CANOPY PILLOW (Midnight of previous day) SWE in inches

WATER YEAR	OCT 1	OCT 15	NOV 1	NOV 15	DEC 1	DEC 15	JAN 1	JAN 15	FEB 1	FEB 15	MAR 1	MAR 15	APR 1	APR 15	MAY 1	MAY 15	JUN 1	JUN 15	JUL 1	DATE SNOW STARTS	MAX SWE	DATE MAX SWE	DATE SNOW ZERO	Snow Covered Days	Snow Free Days
1994	0.0	0.1	0.3	1.7	2.3	2.7	4.6	6.2	7.9	8.0	8.7	9.1	10.1	11.3	10.6	7.0	0.8	0.0	0.0	10/8	11.4	4/16	6/3	239	133
1995	0.0	0.0	0.6	1.4	2.7	2.9	4.0	4.8	5.6	6.4	6.3	6.9	10.0	11.2	11.7	12.8	10.1	6.2	0.0	10/15	12.8	5/14	6/25	254	116
1996	0.0	0.2	0.5	1.2	2.5	3.1	3.4	4.9	5.6	6.1	7.1	7.9	10.3	10.4	11.7	11.7	9.3	0.0	0.0	10/20	12.6	5/11	6/12	237	126
1997	0.0	0.0	1.0	1.3	3.0	3.9	7.2	8.0	9.0	10.3	10.9	11.8	13.2	14.9	14.8	13.7	9.3	0.0	0.0	10/17	15.8	5/9	6/12	239	114
1998	0.0	0.7	1.0	1.2	1.8	1.9	2.5	3.1	4.1	4.2	4.5	5.4	6.5	8.0	7.3	4.3	0.1	0.0	0.0	10/5	8.5	4/22	6/2	241	155
1999	0.0	0.0	0.0	0.7	2.2	3.3	4.6	6.3	7.1	7.7	8.5	8.6	9.1	10.4	9.9	10.9	6.3	0.8	0.0	11/5	11.3	5/18	6/16	224	157
2000	0.0	0.0	0.0	0.0	1.2	1.9	4.5	4.9	5.7	6.6	6.9	7.7	9.6	10.8	9.9	9.5	3.4	0.0	0.0	11/21	11.0	4/18	6/7	201	125
2001	0.0	0.4	0.1	0.6	1.5	1.6	2.7	2.9	3.6	4.0	4.5	5.4	6.2	7.6	7.1	4.2	0.0	0.0	0.0	10/11	8.2	4/25	5/27	229	137
2002	0.0	0.5	0.5	0.2	0.9	1.4	3.4	3.8	4.0	4.5	5.0	5.5	6.7	6.7	8.0	8.7	4.2	0.0	0.0	10/12	9.2	5/12			
2003																									
2004																									
2005																									
AVG 1971-2000	0.0	0.2	0.6	1.1	2.3	2.9	4.4	5.4	6.2	6.8	7.3	8.0	9.7	11.0	10.8	9.9	6.0	0.9	0.0	10/19	11.9	5/7	6/13	235	130

Appendix 2. (Continued)

Tenderfoot Creek Experimental Forest

STRINGER CREEK PILLOW (Midnight of previous day) SWE in inches

WATER YEAR	OCT 1	OCT 15	NOV 1	NOV 15	DEC 1	DEC 15	JAN 1	JAN 15	FEB 1	FEB 15	MAR 1	MAR 15	APR 1	APR 15	MAY 1	MAY 15	JUN 1	JUN 15	JUL 1	DATE SNOW STARTS	MAX SWE	DATE MAX SWE	DATE SNOW ZERO	Snow Covered Days	Snow Free Days
1996	0.0	0.2	0.7	1.6	3.3	4.1	4.4	6.4	7.3	8.0	9.3	11.3	11.5	11.4	11.3	10.3	2.7	0.0	0.0	10/20	12.0	5/10	6/2	227	137
1997	0.0	0.0	1.0	1.4	3.5	4.3	7.6	8.9	9.7	10.9	11.9	12.5	14.0	15.7	13.1	5.8	0.0	0.0	0.0	10/18	16.1	4/12	5/20	215	134
1998	0.0	0.2	0.0	0.2	1.0	1.6	2.7	3.3	5.4	5.6	5.9	7.1	8.0	8.8	4.1	0.6	0.0	0.0	0.0	11/1	8.9	4/20	5/5	186	184
1999	0.0	0.0	0.0	0.9	2.6	3.4	4.4	6.5	7.3	8.1	9.2	9.3	9.1	9.5	4.7	2.3	0.0	0.0	0.0	11/6	9.6	4/6	5/20	195	181
2000	0.0	0.0	0.0	0.0	1.4	2.4	5.4	5.9	6.8	7.5	8.0	9.1	10.8	10.7	4.6	0.7	0.0	0.0	0.0	11/18	11.7	4/3	5/6	176	176
2001	0.0	0.3	0.1	1.0	2.2	2.5	4.0	4.3	5.4	5.9	6.4	7.9	8.7	10.1	5.9	0.0	0.0	0.0	0.0	10/30	10.3	4/15	5/11	194	170
2002	0.0	0.0	0.5	0.4	1.2	1.8	1.8	3.5	4.6	5.7	6.8	7.7	9.2	7.6	7.9	5.2	0.0	0.0	0.0	10/25	9.2	4/4	5/21	207	
2003																									
2004																									
2005																									
AVG 1971-2000	0.0	0.1	0.4	1.1	2.6	3.4	5.1	6.4	7.4	8.1	8.7	9.8	11.0	11.8	8.0	3.7	0.7	0.0	0.0	10/26	11.8	4/22	5/21	205	160

Appendix 3. Estimated monthly snow water equivalent for open snow courses on Tenderfoot Creek Experimental Forest for period of record.

Tenderfoot Creek Experimental Forest

BUBBLING SPRINGS SNOW COURSE 10C17 Elev: 7430 ft Estimated SWE in inches

WATER YEAR	OCT 1	NOV 1	DEC 1	JAN 1	FEB 1	MAR 1	APR 1	MAY 1	MAY 15	JUN 1	MELT-OUT DATE
1993	0.0	1.8	4.2	7.2	10.6	12.0	14.0	17.3	13.4	0.0	6/1
1994	0.0	0.5	3.7	8.4	12.2	13.0	14.5	11.3	3.5	0.0	5/26
1995	0.0	1.8	4.9	7.4	10.0	10.7	15.0	19.4	19.5	12.7	6/18
1996	0.0	1.2	4.8	6.4	9.4	11.2	14.8	16.4	14.6	8.8	6/9
1997	0.0	1.7	5.1	11.3	14.0	17.4	20.9	22.4	19.3	9.6	6/10
1998	0.0	1.7	3.5	4.9	8.4	9.5	12.3	11.6	5.0	0.0	5/31
1999	0.0	0.1	4.1	7.5	11.2	13.5	13.6	13.3	13.4	2.9	6/8
2000	0.0	0.1	2.4	7.7	9.4	11.0	14.7	12.8	10.1	0.0	5/29
2001	0.0	0.2	3.0	5.7	7.5	9.4	12.7	12.5	3.5	0.0	5/21
2002	0.0	1.8	3.3	4.5	8.0	10.8	14.2	15.8	15.4	5.6	6/9
2003											
2004											
2005											
AVG 71-00	0.0	1.0	4.2	7.8	10.4	12.2	15.3	16.0	12.4	5.2	6/4

Appendix 3. (continued)

Tenderfoot Creek Experimental Forest

COUNTY LINE SNOW COURSE 10C18 Elev: 7810 ft Estimated SWE in inches

WATER YEAR	OCT 1	NOV 1	DEC 1	JAN 1	FEB 1	MAR 1	APR 1	MAY 1	MAY 15	JUN 1	MELT-OUT DATE
1993	0.0	1.9	4.5	7.7	11.2	12.8	14.9	20.1	17.0	3.1	6/5
1994	0.2	1.1	4.8	10.3	15.6	17.0	19.4	19.2	11.8	0.0	5/31
1995	0.0	2.4	6.0	8.4	11.7	13.3	16.9	21.4	22.5	15.5	6/20
1996	0.0	1.5	5.6	7.3	10.9	13.3	17.9	20.0	17.8	12.5	6/16
1997	0.0	1.8	5.3	11.5	14.7	18.1	21.5	23.0	19.8	10.3	6/12
1998	0.0	1.8	3.8	5.3	9.2	10.3	13.3	13.0	8.8	3.3	6/9
1999	0.0	0.2	4.8	8.7	13.0	15.7	15.8	16.2	16.7	7.3	6/12
2000	0.0	0.2	2.7	8.0	9.9	11.5	15.4	15.0	12.8	1.5	6/3
2001	0.0	0.3	3.3	6.1	8.1	10.1	13.6	13.8	5.5	0.0	5/24
2002	0.0	2.0	3.4	4.7	8.2	10.9	14.3	16.0	16.4	7.3	6/15
2003											
2004											
2005											
AVG 71-00	0.0	1.3	4.8	8.6	11.7	13.9	17.1	18.9	16.0	8.2	6/9

Appendix 3. (continued)

Tenderfoot Creek Experimental Forest

DRY PARK SNOW COURSE 10C19 Elev: 7420 ft Estimated SWE in inches

WATER YEAR	OCT 1	NOV 1	DEC 1	JAN 1	FEB 1	MAR 1	APR 1	MAY 1	MAY 15	JUN 1	MELT-OUT DATE
1993	0.0	1.7	4.1	7.0	10.2	11.5	13.5	15.6	10.1	0.0	5/26
1994	0.0	0.8	4.1	9.0	13.5	14.7	16.9	15.3	7.7	0.0	5/22
1995	0.0	1.8	4.8	7.2	9.6	10.2	13.7	17.7	17.8	7.1	6/12
1996	0.0	1.2	4.6	6.1	9.2	11.4	15.6	17.3	15.4	9.7	6/10
1997	0.0	1.7	5.2	11.4	14.1	16.6	18.9	20.2	17.4	6.8	6/7
1998	0.0	1.7	3.6	5.1	8.8	9.8	12.8	12.1	5.5	0.0	6/1
1999	0.0	0.1	4.3	7.8	11.7	14.1	14.2	13.9	14.0	4.5	6/9
2000	0.0	0.1	2.2	7.0	8.6	10.1	13.4	11.7	9.2	0.0	5/27
2001	0.0	0.2	2.8	5.3	7.1	8.8	11.9	11.8	3.3	0.0	5/20
2002	0.0	1.7	3.0	4.2	7.3	10.0	13.1	14.5	14.1	4.3	6/8
2003											
2004											
2005											
AVG 71-00	0.0	1.1	4.2	7.7	10.4	12.2	15.1	15.8	12.1	4.3	6/2

Appendix 3. (continued)

Tenderfoot Creek Experimental Forest

FARNES MEADOW SNOW COURSE 10C20 Elev: 7400 ft Estimated SWE in inches

WATER YEAR	OCT 1	NOV 1	DEC 1	JAN 1	FEB 1	MAR 1	APR 1	MAY 1	MAY 15	JUN 1	MELT-OUT DATE
1993	0.0	1.7	4.2	7.2	10.4	11.9	13.8	16.5	11.0	0.0	5/28
1994	0.0	0.9	4.4	9.6	15.4	17.2	20.4	21.3	13.9	0.0	5/28
1995	0.0	1.8	5.0	7.6	10.3	11.1	15.7	20.2	20.3	13.5	6/19
1996	0.0	1.2	4.6	6.1	9.5	12.3	17.7	19.7	17.5	12.1	6/14
1997	0.0	1.7	5.1	11.3	14.0	17.0	20.0	21.4	18.4	8.3	6/9
1998	0.0	1.7	3.5	4.9	8.5	9.5	12.4	11.7	5.1	0.0	5/31
1999	0.0	0.2	4.6	8.4	12.5	15.0	15.2	14.9	15.0	5.1	6/9
2000	0.0	0.1	2.4	7.7	9.4	11.0	14.7	12.8	10.1	0.0	5/29
2001	0.0	0.2	3.2	6.0	7.9	9.9	13.3	13.2	3.7	0.0	5/22
2002	0.0	1.0	2.9	4.1	7.2	9.7	12.8	14.2	13,8	4.0	6/8
2003											
2004											
2005											
AVG 71-00	0.0	1.1	4.4	8.1	11.0	13.1	16.5	17.7	13.9	6.0	6/5

Appendix 3. (continued)

Tenderfoot Creek Experimental Forest

LONESOME CREEK SNOW COURSE 10C21 Elev:6970 ft Estimated SWE in inches

WATER YEAR	OCT 1	NOV 1	DEC 1	JAN 1	FEB 1	MAR 1	APR 1	MAY 1	MAY 15	JUN 1	MELT-OUT DATE
1993	0.0	1.5	3.7	6.4	9.3	10.6	12.4	12.4	9.4	0.0	5/24
1994	0.0	0.4	3.1	7.1	10.8	11.8	13.7	10.5	2.1	0.0	5/19
1995	0.0	1.5	4.2	6.3	8.7	9.4	13.7	16.3	15.4	5.9	6/9
1996	0.0	0.9	3.7	5.1	8.0	10.0	13.7	13.3	11.3	4.2	6/7
1997	0.0	1.3	4.2	8.9	11.3	14.2	17.1	17.1	11.1	0.0	5/28
1998	0.0	0.7	2.0	3.7	6.8	7.6	10.1	7.4	0.0	0.0	5/10
1999	0.0	0.1	3.4	5.8	9.4	11.5	11.6	8.7	6.5	0.0	5/26
2000	0.0	0.0	1.9	6.5	8.2	9.6	12.8	8.3	3.9	0.0	5/20
2001	0.0	0.1	2.8	5.2	7.0	8.4	11.4	9.4	0.9	0.0	5/17
2002	0.0	1.1	2.3	3.1	6.4	9.0	12.0	13.3	12.3	1.6	6/3
2003											
2004											
2005											
AVG 71-00	0.0	0.7	3.4	6.5	8.9	10.6	13.4	12.1	7.3	1.5	5/27

Appendix 3. (continued)

Tenderfoot Creek Experimental Forest

ONION PARK SNOW COURSE 10C22 Elev: 7410 ft Estimated SWE in inches

WATER YEAR	OCT 1	NOV 1	DEC 1	JAN 1	FEB 1	MAR 1	APR 1	MAY 1	MAY 15	JUN 1	MELT-OUT DATE
1993	0.0	1.7	4.1	7.0	10.2	11.5	13.5	14.6	9.8	0.0	5/29
1994	0.0	0.6	4.2	9.6	14.1	15.1	16.9	15.0	7.3	0.0	5/26
1995	0.0	1.8	4.8	7.2	10.0	10.9	15.8	20.4	20.5	9.6	6/16
1996	0.0	1.0	4.1	5.5	8.7	11.6	17.3	19.3	17.2	11.8	6/13
1997	0.0	1.8	5.5	12.2	15.1	18.1	19.7	21.3	18.0	5.0	6/6
1998	0.0	1.6	3.3	4.7	8.2	9.2	11.9	11.2	4.6	0.0	5/30
1999	0.0	0.1	4.3	7.8	11.7	14.1	14.2	13.9	14.0	4.5	6/9
2000	0.0	0.1	2.6	8.3	10.2	11.9	15.9	13.8	10.9	0.0	5/29
2001	0.0	0.2	2.8	5.2	7.0	8.7	11.7	11.6	3.2	0.0	5/20
2002	0.0	1.9	3.3	4.6	8.1	11.0	14.5	16.1	15.7	5.9	6/9
2003											
2004											
2005											
AVG 71-00	0.0	1.0	4.2	7.9	10.7	12.6	15.8	16.5	12.7	4.7	6/1

Appendix 3. (continued)

Tenderfoot Creek Experimental Forest

STRINGER CREEK SNOW COURSE 10C23 Elev: 6550 ft Estimated SWE in inches

WATER YEAR	OCT 1	NOV 1	DEC 1	JAN 1	FEB 1	MAR 1	APR 1	MAY 1	MAY 15	JUN 1	MELT-OUT DATE
1993	0.0	0.5	3.5	5.7	9.4	10.6	10.5	11.8	6.1	0.0	5/21
1994	0.0	0.4	3.2	7.3	10.8	11.5	12.8	8.8	0.0	0.0	5/13
1995	0.0	0.9	3.1	5.1	7.2	7.8	11.2	12.9	9.7	0.2	6/2
1996	0.0	0.7	3.2	4.2	6.9	8.6	11.7	11.2	9.4	1.6	6/1
1997	0.0	1.1	4.0	8.6	10.9	12.6	14.1	13.3	5.9	0.0	5/21
1998	0.0	0.0	1.0	2.6	5.2	5.7	7.7	4.0	0.4	0.0	5/5
1999	0.0	0.0	2.2	3.7	6.1	7.7	7.6	3.9	1.9	0.0	5/19
2000	0.0	0.0	1.4	5.5	6.9	8.1	10.9	4.6	0.7	0.0	5/6
2001	0.0	0.1	2.4	4.2	5.7	6.8	9.2	6.2	0.0	0.0	5/11
2002	0.0	0.5	1.2	1.9	4.7	7.0	9.4	8.1	5.4	0.0	5/21
2003											
2004											
2005											
AVG 71-00	0.0	0.4	2.8	5.5	7.8	9.0	11.0	8.9	4.1	0.3	5/19

Appendix 3. (continued)

Tenderfoot Creek Experimental Forest

SUN CREEK SNOW COURSE 10C24 Elev: 7040 ft Estimated SWE in inches

WATER YEAR	OCT 1	NOV 1	DEC 1	JAN 1	FEB 1	MAR 1	APR 1	MAY 1	MAY 15	JUN 1	MELT-OUT DATE
1993	0.0	0.6	4.6	7.6	12.6	14.2	14.1	15.4	9.4	0.0	5/24
1994	0.0	0.5	4.0	9.0	14.1	15.5	18.0	16.2	8.2	0.0	5/21
1995	0.0	1.7	4.7	7.1	9.6	10.3	14.4	18.6	18.6	7.7	6/13
1996	0.0	1.0	4.0	5.3	8.6	11.1	15.9	16.6	14.3	8.4	6/8
1997	0.0	1.5	4.9	10.5	13.2	15.8	18.2	18.2	11.8	0.0	5/31
1998	0.0	0.8	2.1	3.8	7.1	7.8	10.5	8.1	0.6	0.0	5/17
1999	0.0	0.1	3.8	6.4	10.5	12.7	12.9	9.6	7.2	0.0	5/27
2000	0.0	0.0	2.1	7.1	9.0	10.5	14.0	9.1	4.3	0.0	5/21
2001	0.0	0.1	2.7	4.9	6.6	8.0	10.9	9.0	0.9	0.0	5/17
2002	0.0	1.2	2.5	3.4	6.8	9.7	12.9	14.3	13.4	2.9	6/4
2003											
2004											
2005											
AVG 71-00	0.0	0.7	3.9	7.2	10.3	12.0	14.9	14.1	9.1	2.5	5/28

Appendix 4. Estimated monthly precipitation for period of record for precipitation gages on Tenderfoot Creek Experimental Forest.

Tenderfoot Creek Experimental Forest

BUBBLING SPRINGS STORAGE GAGE MC17 Elev: 7430 ft Precipitation in inches

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1993	1.9	2.1	2.6	2.8	1.4	2.4	4.2	4.2	5.0	8.4	7.4	2.3	44.7
1994	2.3	2.3	3.4	3.7	1.1	2.2	3.8	1.8	2.4	1.8	0.4	0.4	25.6
1995	2.4	2.2	1.9	2.6	0.8	4.0	4.1	3.8	6.1	4.3	2.0	2.5	36.7
1996	2.8	2.6	1.2	2.7	2.0	3.4	2.7	5.8	2.1	1.4	0.6	2.3	29.6
1997	1.9	2.5	4.8	2.0	2.9	2.4	3.2	3.8	6.5	3.0	2.6	1.3	36.9
1998	2.4	1.4	1.2	2.8	0.6	1.4	3.0	4.3	6.5	2.9	1.5	1.5	29.5
1999	0.9	3.2	2.7	2.4	1.8	1.1	3.1	3.9	3.5	1.2	4.7	1.2	29.7
2000	0.9	1.1	4.3	1.7	1.3	3.6	3.0	3.5	4.3	1.3	0.8	2.8	28.6
2001	2.1	1.8	1.9	1.4	1.3	2.3	3.4	1.4	3.2	3.5	0.8	3.4	26.5
2002	1.9	1.1	0.7	2.7	2.1	2.4	1.9	3.7					
2003													
2004													
2005													
71-00 AVG	1.8	2.7	3.4	3.3	2.3	3.0	2.9	3.5	3.2	2.5	2.0	1.7	32.3

Note: Data revised 1/30/2002 PF

Appendix 4 (continued)

Tenderfoot Creek Experimental Forest

COUNTY LINE STORAGE GAGE MC18 Elev: 7810 ft Precipitation in inches

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1993	2.5	2.0	2.6	2.8	1.5	2.5	4.0	3.7	5.4	9.5	6.5	2.8	45.8
1994	2.1	2.4	3.5	4.2	1.0	2.2	4.1	2.1	2.6	1.9	0.5	0.4	27.0
1995	2.0	1.9	1.6	2.2	1.2	4.2	4.8	4.4	7.2	5.3	2.3	2.6	39.7
1996	2.7	2.7	1.1	2.8	2.0	3.5	2.8	6.1	2.2	1.5	0.9	2.4	30.7
1997	1.9	2.7	4.8	2.1	3.1	2.4	3.9	4.6	8.1	3.7	3.2	1.6	42.1
1998	2.3	1.4	1.2	2.7	0.7	1.6	3.3	3.9	7.0	3.0	1.6	1.6	30.3
1999	0.9	3.1	2.6	2.3	2.0	1.1	3.6	4.5	4.3	1.0	4.4	1.1	30.9
2000	0.7	1.0	3.7	1.4	1.3	3.6	3.2	3.8	4.8	1.2	0.7	2.9	28.3
2001	1.9	1.6	1.7	1.3	1.3	2.4	3.4	1.4	3.3	3.6	0.7	3.5	26.1
2002	1.5	1.0	0.6	2.3	2.2	2.6							
2003													
2004													
2005													
71-00 AVG	1.9	2.8	3.7	3.6	2.5	3.3	3.1	3.6	3.2	2.5	2.0	1.6	33.8

Note: Data revised 1/30/2002 PF

Appendix 4. (continued)

Tenderfoot Creek Experimental Forest

DRY PARK STORAGE GAGE MC19 Elev: 7420 ft Precipitation in inches

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1993	2.0	1.7	2.2	2.3	1.4	2.4	4.0	3.8	5.9	10.2	7.1	3.1	46.1
1994	2.6	2.2	3.1	3.2	0.8	1.8	4.1	2.2	2.4	2.1	0.4	0.5	25.4
1995	2.3	2.0	1.8	2.2	1.1	3.7	4.5	4.2	6.8	5.0	2.5	2.7	38.8
1996	2.5	2.7	1.1	2.6	2.0	3.4	2.8	6.1	3.4	1.5	0.8	2.5	31.4
1997	1.6	2.3	4.2	1.8	2.6	2.1	3.3	3.8	6.7	3.0	2.6	1.7	35.7
1998	2.3	1.4	1.2	2.7	0.8	2.0	2.7	3.6	6.4	2.7	1.1	1.3	28.2
1999	0.8	2.8	2.4	2.1	1.9	1.2	3.2	4.5	3.7	0.9	4.5	0.6	28.6
2000	0.8	0.9	3.7	1.4	1.4	3.5	3.2	3.8	4.7	1.2	0.7	2.8	28.1
2001	2.0	1.7	2.0	1.4	1.2	2.2	3.2	1.3	3.0	3.3	0.7	3.1	25.1
2002	1.6	1.0	0.7	2.3									
2003													
2004													
2005													
71-00 AVG	1.8	2.7	3.4	3.3	2.3	3.0	2.9	3.5	3.2	2.5	2.0	1.7	32.3

Note: Data revised 1/30/2002 PF

Appendix 4. (continued)

Tenderfoot Creek Experimental Forest

FARNES MEADOW STORAGE GAGE MC20 Elev: 7400 ft Precipitation in inches

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1993	2.3	1.8	2.4	2.6	1.4	2.5	3.6	3.7	6.1	10.1	7.2	2.9	46.6
1994	2.5	2.4	3.4	4.1	1.1	2.1	4.3	2.3	2.5	2.0	0.4	0.5	27.6
1995	2.6	2.2	2.0	2.3	1.1	3.7	4.5	4.2	6.7	5.0	2.2	2.5	39.0
1996	2.8	2.6	1.1	2.7	2.0	3.5	2.9	6.6	2.4	1.6	0.9	2.5	31.6
1997	1.9	2.6	4.7	2.1	3.1	2.5	3.5	4.1	7.4	3.4	2.9	1.5	39.7
1998	2.3	1.4	1.1	2.7	0.6	1.6	2.7	3.9	7.1	3.1	1.4	1.5	29.4
1999	0.9	3.3	2.7	2.5	1.9	1.2	3.1	4.0	3.1	2.4	4.3	1.1	30.5
2000	0.8	1.1	3.9	1.6	1.4	3.7	3.2	3.9	4.6	1.2	0.6	2.8	28.8
2001	1.8	1.5	1.7	1.2	1.1	1.9	3.4	1.4	3.3	3.6	0.9	3.4	25.2
2002	1.5	1.0	0.6	2.3	1.7	2.0							
2003													
2004													
2005													
71-00 AVG	1.8	2.8	3.5	3.5	2.4	3.1	3.0	3.6	3.4	2.6	2.1	1.7	33.5

Note: Data revised 1/30/2002 PF

Appendix 4. (continued)

Tenderfoot Creek Experimental Forest

LONESOME CREEK STORAGE GAGE MC21 Elev: 6970 ft Precipitation in inches

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1993	1.9	2.5	2.3	2.7	1.7	2.1	3.6	4.3	5.4	8.2	6.8	2.2	43.7
1994	2.1	1.9	3.0	3.4	1.1	1.8	3.7	2.1	2.0	1.6	0.5	0.2	23.4
1995	2.0	1.9	1.6	2.3	1.1	3.7	3.8	3.9	5.8	4.3	2.2	2.5	35.1
1996	2.8	2.3	1.1	2.8	1.2	3.5	2.6	5.6	2.1	0.8	1.3	2.4	28.5
1997	1.6	2.5	4.0	2.1	2.5	2.4	2.7	3.9	5.4	2.7	2.4	1.3	33.5
1998	2.2	1.1	1.5	2.6	0.7	1.9	2.1	3.3	6.8	2.6	2.1	1.4	28.3
1999	0.6	2.3	2.1	2.9	1.9	0.9	2.3	3.5	4.0	1.2	3.0	1.1	25.8
2000	0.7	1.5	3.9	1.4	1.3	3.0	2.6	3.2	3.7	1.5	0.7	2.7	26.2
2001	2.2	1.5	2.0	1.4	1.1	2.4	2.9	1.4	4.0	3.1	0.7	3.0	25.7
2002	1.8	0.9	0.7	2.3	1.9	2.0	1.9	3.6					
2003													
2004													
2005													
71-00 AVG	1.6	2.5	3.1	3.0	2.0	2.6	2.7	3.4	3.3	2.4	2.0	1.7	30.3

Note: Data revised 1/30/2002 PF

Appendix 4. (continued)

Tenderfoot Creek Experimental Forest

ONION PARK STORAGE GAGE MC22 Elev: 7410 ft Precipitation in inches

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1993	2.3	2.0	2.5	2.6	1.4	2.3	4.0	3.9	5.5	9.0	6.9	2.6	45.0
1994	2.2	2.4	3.5	4.2	1.1	2.2	4.3	2.2	2.8	1.9	0.3	0.4	27.5
1995	2.6	2.3	2.0	2.4	1.1	3.9	4.3	4.0	6.8	4.7	2.1	2.7	38.9
1996	3.0	2.5	1.1	2.9	2.2	3.8	2.8	6.1	2.3	1.6	1.3	2.2	31.8
1997	1.9	2.7	4.9	2.2	3.0	2.2	3.4	4.0	7.0	3.0	2.7	1.1	38.1
1998	2.5	1.4	1.3	2.8	0.8	2.3	3.0	3.8	7.0	2.9	1.4	1.5	30.8
1999	1.0	3.4	2.9	2.6	2.0	1.2	3.0	3.8	3.1	2.3	4.2	1.1	30.6
2000	0.9	1.2	4.4	1.7	1.5	3.8	3.1	3.6	4.5	1.2	0.7	2.7	29.3
2001	2.1	1.7	2.0	1.4	1.3	2.3	3.1	1.3	2.8	3.3	0.7	3.0	25.0
2002	1.9	1.2	0.8	2.8	2.1	2.4	2.0	3.8					
2003													
2004													
2005													
71-00 AVG	1.8	2.8	3.5	3.4	2.4	3.1	3.0	3.6	3.3	2.6	2.1	1.7	33.3

Note: Data revised 1/30/2002 PF

Appendix 4. (continued)

Tenderfoot Creek Experimental Forest

ONION PARK TIPSTOR OPEN MC22TO Elev: 7410 ft Precipitation in inches

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1993													
1994										1.58	0.27	0.36	
1995									6.23	4.83	2.06	2.33	
1996	1.53	1.26									0.85	2.33	
1997	0.52	0.70	3.39	2.00	2.43	2.17	2.22	4.45	4.49	2.93	2.32	1.32	28.98
1998	1.50	0.81	1.36	2.45	0.64	2.29	2.21	3.03	5.87	2.10	1.13	1.01	24.40
1999	1.16	0.24	1.46	1.79	0.40	0.89	1.54	1.99	3.50	1.00	2.76	0.75	17.48
2000	0.99	0.98	3.60	1.71	1.23	3.07	2.77	3.10	3.50	1.20	0.58	2.54	25.27
2001	1.81	1.20	1.97	1.10	1.17	2.10	3.21	1.54	3.94	2.91	0.61	2.93	24.49
2002													
2003													
2004													
2005													
71-00 Avg													

REMARKS: Tipstor gage added 9/13/96. Multiply tips X 1.0666 to obtain true precipitation. These values are corrected and are programed into Data pod.
Note: Data revised 1/30/2002 PF

Appendix 4. (continued)

Tenderfoot Creek Experimental Forest

ONION PARK TIPSTOR MODERATE MC22TM Elev: 7410 ft Precipitation in inches

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1993													
1994										0.98	0.13	0.02	
1995									2.18	3.22	1.45	1.81	
1996	0.40	0.73									0.94	1.53	
1997	0.15	0.42								1.25	0.99	0.41	
1998	0.98	0.60	0.85	2.04	0.45	1.77	1.79	1.42	4.76	0.77	1.11	0.02	
1999													
2000													
2001													
2002													
2003													
2004													
2005													
71-00 Avg													

REMARKS: Tipstor gage added 9/13/96. Multiply tips X 1.0666 to obtain true precipitation. These values are corrected and are programed into Data pod.
Note: Data revised 1/30/2002 PF

Appendix 4. (continued)

Tenderfoot Creek Experimental Forest

ONION PARK TIPSTOR DENSE MC22TD Elev: 7430 ft Precipitation in inches

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1993													
1994										0.53	0.18	0.19	
1995									1.76	2.66	1.21	0.18	
1996	0.61	0.38									0.66	1.17	
1997	0.04	0.06											
1998													
1999													
2000													
2001													
2002													
2003													
2004													
2005													
71-00 Avg													

REMARKS: Tipstor gage added 9/13/96. Multiply tips X 1.0666 to obtain true precipitation. These values are corrected and are programed into Data pod.
Note: Data revised 1/30/2002 PF

Appendix 4. (continued)

Tenderfoot Creek Experimental Forest

PASSIONATE CREEK STORAGE GAGE MC25 Elev: 6250 ft Precipitation in inches

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1993													
1994													
1995	1.6	1.3	1.3	2.1	0.9	3.0	3.1	3.7	4.8	4.5	2.5	2.5	31.3
1996	1.3	2.6	1.0	2.4	1.9	1.9	2.1	4.6	2.0	0.6	1.5	2.2	24.1
1997	1.2	2.1	3.2	2.0	1.6	2.0	2.1	3.8	4.7	2.8	2.6	1.4	29.5
1998	1.5	0.8	1.3	2.2	0.6	1.7	1.5	4.6	6.1	2.1	1.9	0.9	25.2
1999	0.5	1.7	1.7	2.2	1.5	0.5	1.9	3.0	3.9	1.1	2.6	1.0	21.6
2000	0.4	1.3	2.7	0.9	1.2	2.2	2.6	2.9	3.5	1.8	0.6	2.4	22.5
2001	1.8	1.1	1.7	1.1	0.7	1.6	3.2	2.2	2.9	2.9	0.8	2.2	22.2
2002	1.3	0.7	0.5	1.8	1.4	1.5	1.5	2.9					
2003													
2004													
2005													
71-00 Avg	1.3	2.0	2.3	2.2	1.5	2.0	2.3	3.2	3.3	2.4	2.0	1.7	26.2

Note: Data revised 1/30/2002 PF

Appendix 4. (continued)

Tenderfoot Creek Experimental Forest

STRINGER CREEK STORAGE GAGE MC23 Elev: 6550 ft Precipitation in inches

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1993	1.8	2.4	1.8	2.4	1.4	1.9	3.1	3.7	5.8	8.7	7.6	2.3	42.9
1994	2.2	1.8	3.0	3.7	1.1	1.8	3.7	2.2	2.2	1.8	0.4	0.4	24.3
1995	1.7	1.8	1.5	2.5	1.0	3.7	3.8	4.4	5.7	5.0	2.8	2.2	36.1
1996	1.4	2.7	1.1	2.9	2.5	2.5	2.6	5.5	2.2	0.5	1.4	2.4	27.7
1997	1.4	2.5	3.9	2.3	2.2	2.4	2.4	4.2	5.8	3.6	3.3	1.6	35.6
1998	1.8	1.0	1.6	2.6	0.7	2.0	1.6	3.8	7.5	2.2	2.0	0.9	27.7
1999	0.6	2.1	2.0	2.7	1.9	0.8	2.2	3.4	5.5	0.7	2.6	1.0	25.5
2000	0.5	1.6	3.4	1.2	1.4	2.7	3.2	3.6	4.3	1.3	0.7	2.7	26.6
2001	2.2	1.2	2.0	1.3	0.9	2.3	2.4	1.5	4.8	3.1	0.4	2.7	24.8
2002	1.7	0.9	0.6	2.2	1.9	7.0	1.8	3.6					
2003													
2004													
2005													
71-00 Avg	1.6	2.5	3.0	2.8	1.9	2.5	2.7	3.4	3.5	2.6	2.2	1.8	30.5

Note: Data revised 1/30/2002 PF

Appendix 4. (continued)

Tenderfoot Creek Experimental Forest

STRINGER CREEK TIPSTOR MC23TO Elev: 6550 ft Precipitation in inches

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1993													
1994													
1995													
1996		1.01											
1997	1.36	2.36	395.00	2.00	2.43	2.27	2.20	4.53	4.35	4.25	3.31	1.68	34.69
1998	1.70	0.91	1.59	2.45	0.63	2.20	1.72	3.62	7.53	2.10	2.63	0.89	27.97
1999	0.80	2.60	2.22	2.95	2.17	1.03	2.16	3.69	4.89	1.08	2.69	1.07	27.35
2000	0.40	1.60	3.86	1.30	1.27	3.72	3.59	3.50	2.58	1.48	0.68	2.72	26.70
2001	1.90	1.46	2.03	1.31	1.02	2.35	2.51	1.43	4.80	3.50	0.46	3.42	26.19
2002													
2003													
2004													
2005													
71-00 Avg													

REMARKS: Tipstor gage added 9/30/96. Multiply tips X 1.1008 to obtain true precipitation after 9/30/96.
Programed into data recorder starting 1999 WY. 1997 and 1998 records corrected.
Note: Data revised 1/30/2002 PF

Appendix 4. (continued)

Tenderfoot Creek Experimental Forest

SUN CREEK STORAGE GAGE MC24 Elev: 7040 ft Precipitation in inches

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1993	1.9	2.1	1.9	2.3	1.7	1.9	3.5	4.4	6.1	9.3	7.9	2.2	45.2
1994	2.1	1.8	2.9	3.2	0.8	1.6	4.0	2.3	2.5	2.0	0.4	0.4	24.0
1995	2.2	2.0	1.8	2.3	0.9	3.2	4.1	4.2	6.3	4.8	2.2	2.7	36.7
1996	2.2	2.6	1.1	2.7	2.1	2.7	2.7	6.0	2.2	0.9	1.2	2.3	28.7
1997	1.6	2.5	4.3	2.2	2.5	2.5	2.7	4.1	6.1	3.3	2.8	1.3	35.9
1998	2.2	1.1	1.5	2.6	0.7	1.9	2.1	3.9	7.3	2.9	1.9	1.4	29.5
1999	0.8	2.6	2.4	2.6	1.9	0.9	2.5	3.5	4.4	1.4	3.1	1.1	27.2
2000	0.6	1.4	3.5	1.3	1.3	2.8	3.0	3.7	4.2	1.7	0.8	2.5	26.8
2001	2.0	1.5	2.0	1.3	1.0	2.0	2.8	1.3	3.9	3.0	0.8	2.8	24.4
2002	1.7	0.9	0.7	2.3	2.0	2.2	1.7	3.3					
2003													
2004													
2005													
71-00 Avg	1.7	2.6	3.2	3.1	2.1	2.7	2.8	3.4	3.4	2.5	2.1	1.7	31.3

REMARKS: Precipitation gage moved summer 1994. Records for 1993 and 1994 adjusted to current location.
Note: Data revised 1/30/2002 PF

Appendix 4. (continued)

Tenderfoot Creek Experimental Forest

UPPER STRINGER STORAGE GAGE MC26 Elev: 6880 ft Precipitation in inches

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
1993													
1994													
1995													
1996													
1997	1.7	2.6	4.4	2.2	2.4	2.5	3.0	3.8	6.2	3.4	2.9	1.4	36.5
1998	2.2	1.1	1.5	2.6	0.7	2.0	2.4	3.9	7.7	2.6	1.9	1.2	29.8
1999	0.7	2.7	2.3	2.6	2.0	1.0	2.6	3.8	4.9	0.9	3.4	1.1	28.0
2000	0.7	1.3	3.8	1.4	1.4	3.4	3.1	3.8	4.7	1.5	0.7	2.8	28.6
2001	2.2	1.6	2.0	1.4	1.2	2.5	3.0	1.4	4.2	3.3	1.4	2.5	26.7
2002	1.8	1.0	0.6	2.4	2.2	2.2							
2003													
2004													
2005													
71-00 Avg	1.6	2.5	3.1	3.1	2.1	2.7	2.8	3.5	3.5	2.6	2.2	1.8	31.5

Note: Data revised 1/30/2002 PF

Appendix 5. Monthly precipitation averages for stations on and near Tenderfoot Creek Experimental Forest for 1971-2000 base period used in Figure 3.

TENDERFOOT CREEK EXPERIMENTAL FOREST

1971-2000 PRECIPITATION AVERAGES, IN INCHES

STATION	SITE NAME	ELEV, ft	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
10C22S	Onion Park	7410	1.80	2.80	3.50	3.40	2.40	3.10	3.00	3.60	3.30	2.60	2.10	1.70	33.30
10C23S	Stringer Creek	6550	1.60	2.50	3.00	2.80	1.90	2.50	2.70	3.40	3.50	2.60	2.20	1.80	30.50
10C09S	Deadman Creek	6450	1.40	2.20	2.68	2.54	1.67	2.24	2.42	3.05	3.17	2.33	2.03	1.64	27.36
MT3157	Fort Logan 4ESE	4710	0.60	0.34	0.32	0.33	0.21	0.51	0.88	2.07	1.92	1.53	1.25	1.12	11.08
MT5712	Millegan 14 SE	4970	1.15	0.84	1.01	0.95	0.51	1.36	1.66	2.73	2.59	2.19	1.60	1.81	18.40
MT6008	Neihart 8 NNW	5230	1.38	1.01	1.01	0.95	0.66	1.36	1.84	3.49	3.32	2.28	2.14	1.98	21.42
10C06S	Spur Park	8100	2.21	3.48	4.59	4.59	3.11	3.98	3.61	4.10	3.52	2.86	2.17	1.83	40.06
MT8930	White Sulphur Spr 2	5040	0.99	0.44	0.47	0.47	0.38	0.84	1.18	2.29	2.21	1.52	1.20	1.23	13.22
MTMC16	White Sulphur Spr 10	5440	0.76	0.78	0.75	0.85	0.51	0.90	1.22	2.18	2.44	1.88	1.46	1.31	15.04

Appendix 6.

SNOWPACK COMPARISON BETWEEN AN OPENING AND A LODGEPOLE PINE STAND

Ward W. McCaughey[1/] and Phillip E. Farnes[2/]

ABSTRACT

In the fall of 1993, two snow pillows were installed at a permanent data site located at Onion Park Research Natural Area on the Tenderfoot Creek Experimental Forest in central Montana. One pillow is located in a small open meadow, and the second pillow is located 25 m away under a dense forest canopy of lodgepole pine. The two pillows were installed to standard specifications for a Natural Resources Conservation Service snow telemetry data site. Measurements of snow water equivalent (SWE) were monitored on both pillows with a continuous water level recorder from 1993 through 1995 and electronic data recorder from 1995 to present. Manual manometer levels were read during each site visit to verify data recorder values. The annual maximum SWE on the canopy pillow has averaged 77 percent of the open pillow over the winters from 1993 to 2000. Melt rates under the canopy have averaged 46 percent of that in the open. On average, final melt-out of the canopy pillow is 9 days after the open pillow. Results from this research will be used to model changes in streamflow volume and timing of peak streamflow after forest modifications in 2001. This information should also be useful for hydrologic modeling or for modeling hydrologic changes after a forest has been harvested, burned or changed in structure due to age, disease, insect infestations or blowdown.

INTRODUCTION

Numerous studies have compared periodic measurements of snow accumulation and melt between forested and open areas using the Federal snow sampler (Gary and Troendle 1982, Farnes and Hartman 1989, Skidmore *et al.* 1994). Moore and McCaughey (1997) compared snow accumulation between canopy and open snow water equivalent (SWE) on the Tenderfoot Creek Experimental Forest (TCEF) using periodic snow sampling during the 1995-96 winter. Farnes *et al.* (2001) using sampling data from Moore and McCaughey and from several other locations and studies in Montana developed a relationship between SWE and percent canopy using data from 179 stands with 129 being comprised of primarily lodgepole pine (*Pinus contorta* Dougl. var. *latifolia*). This relationship indicated that pre-melt SWE under a mature lodgepole pine forest would average 77 to 78 percent of SWE in an open area. To our knowledge, this study is the first involving continuous recording of SWE using non-destructive measurements (snow pillows) at co-located open and forested sites. The physical location of the open site is comparable to that of Snow Telemetry (SNOTEL) sites installed by the Natural Resources Conservation Service (NRCS) throughout the western United States. The canopy

Paper presented at the 69th Annual Meeting of the Western Snow Conference, April 17-19, 2001, Sun Valley, Idaho.

1/ Research Forester and Manager of Tenderfoot Creek Experimental Forest, U.S.D.A. Forest Service, Rocky Mountain Research Station, Montana State University, Bozeman, MT.

2/ Snowcap Hydrology, Bozeman, MT.

snow pillow in Onion Park Research Natural Area was installed within a lodgepole pine forest where the SWE would be fairly representative of the snowpacks under lodgepole pine canopies in forests throughout the Rocky Mountain West. The relationship between snowpacks under forest canopies and in openings has been an important component for modeling water yield changes. These changes are associated with removal of forest canopy through management prescriptions, wildfire, disease epidemics, insect infestations, or the opening of forest canopies through natural mortality.

STUDY AREA

The Tenderfoot Creek Experimental Forest is located in the Little Belt Mountains of central Montana, 39 km north of White Sulphur Springs and about 19 km northwest of Kings Hill on Highway 89. The nearest metropolitan area to TCEF is Great Falls, Montana, which is a 72 km drive to the northwest. The majority of the 3,692 ha experimental forest is drained by Tenderfoot Creek which flows westerly into the Smith River, a tributary to the Missouri River. The experimental forest is located within the Lewis and Clark National Forest but is administered by the Rocky Mountain Research Station (Farnes *et al.* 1995).

Established in 1961 for watershed research, TCEF has a 1961-1990 average annual precipitation of 890 mm, an elevational range from 1,838 to 2,421 m, and a mean elevation of 2206 m. Hydrologic monitoring was initiated in 1991 as part of baseline data monitoring for proposed research studies.

The experimental forest is about 9 percent non-forested, 42 percent single-aged lodgepole pine stands, and 49 percent two-aged stands that are predominately lodgepole pine mixed with subalpine fir (*Abies lasiocarpa*) and Engelmann Spruce (*Picea engelmannii*) (Barrett 1993). The oldest stands on TCEF last burned in 1580 while the most recent natural burn affecting a significant area was in 1902. There have been three fires since 1902 and all three combined have burned less than 11 ha. Fires have occurred on TCEF an average of every 32 years over the past 420 years.

The Onion Park study site is comprised of a small natural opening surrounded by a dense two-age lodgepole pine stand that burned in 1765 and again in 1873. It is in the eastern part of the experimental forest and is within the 475 ha Onion Park Research Natural Area. The study site has a 1961-1990 average annual precipitation of 892 mm and the elevation is 2,259 m. The 1961-1990 estimated average April 1 SWE is 340 mm on the open pillow and 249 mm on the canopy pillow (Farnes *et al.* 1999).

Two 3.05-m-diameter, nylon-reinforced neoprene snow pillows were installed in the fall of 1993 and were filled with 400 l of antifreeze solution that was approximately 50 percent water and 50 percent methanol. One pillow is located in the open, the other is 25 m to the north under a forest canopy. The open snow pillow has no canopy within 0-30° cone as measured with the photocanopyometer (Codd 1959), while the canopy pillow has 63 percent canopy coverage. Spherical densiometer readings were 8 percent canopy for the open pillow compared to 74 percent for the canopy pillow. The basal area for the open pillow was 8 m^2/ha compared to 35.6 m^2/ha for the canopy pillow. Weather instruments at the study site measure precipitation, humidity, and air and soil temperature. Within TCEF, there are additional snow, precipitation, climate, and streamflow monitoring sites.

METHODS

Except for short periods of recorder malfunctions, a continuous trace of snow water equivalent data has been collected since the fall of 1993; missing records were estimated from relationships with nearby sites. The initial data was collected using water level chart recorders on a float and pulley system in a stilling well - in 1995 the chart recorders were replaced with an electronic data recorder. The recorders are housed in an instrument shelter along with the stilling well and manometer for each pillow. The manometer was read to the nearest millimeter during each site visit, and those manometer readings were compared to chart or electronic data recorder values. The chart and electronic recorders measured and recorded SWE to the nearest 3 mm. All measurements were corrected for specific gravity of the antifreeze solution in the pillows. The midnight SWE was determined for each pillow for each daily value. Comparisons were made between the start of snow accumulation, daily accumulation, annual maximum SWE, date of maximum accumulation, melt-out rate over comparable days, and the melt-out date.

RESULTS

The actual date snow began to accumulate varied between years depending on early season snowfall and melt. Start of accumulation began as early as October 8 and 9 for canopy and open pillows, respectively. At maximum accumulation, the canopy pillow accumulated an average of 77 percent of the snow water equivalent measured in the open during the 7-year measurement period (Table 1). At maximum snow accumulation, the canopy pillow SWE varied from a low of 66 percent of the open pillow SWE in 1998 to a high of 87 percent in 1999. Maximum canopy and open SWE ranged respectively from a high of 401 and 485 mm in 1997 (Figure 1) to a low of 216 and 318 mm in 1998 (Figure 2). The maximum snow accumulation averaged 303 mm for the canopy and 395 mm for the open snow pillow throughout the 7-year measurement period.

The date of maximum snow accumulation occurred as late as May 14 for open and May 18 for canopy pillows. The date of maximum accumulation was near or on the same date during the seven-year study period except when dates varied by almost a month in 1999 and eleven days in 2000. The average date for maximum accumulation was April 27 for open and May 3 for canopy pillows.

Average melt rates under the canopy averaged 46 percent of those in the open over comparable time periods when both pillows had melting snow. Melt rates varied from 40 percent in 1999 to 53 percent in 1997 (Table 2). Melt-out occurred under the canopy an average of 9 days after melt-out in the open and varied from 5 days in 1996 to 13 days in 1999. Figure 3 shows the 7-year average daily SWE for the open and closed canopy pillows in Onion Park. Average daily melt rates ranged from 6.0 to 13.0 mm/day for canopy and open snow pillows, respectively, for the 7-year measurement period. Snow on the canopy pillow melted-out an average of 9 days later than the open pillow.

Table 1. Comparisons between open and canopy pillows at Onion Park on the Tenderfoot Creek Experimental Forest showing start of accumulation, maximum snow water equivalent (SWE), and date of maximum SWE for the period 1994 - 2000.

	Start of Accumulation		**Maximum SWE**			**Date of Maximum Accumulation**	
Water Year	Open	Canopy	Open mm	Canopy mm	Canopy as % Open	Open	Canopy
1994	10/19	10/08	404	290	72	4/16	4/16
1995	10/15	10/15	457	325	71	5/14	5/14
1996	10/23	10/20	399	320	80	5/11	5/11
1997	10/09	10/17	485	401	83	5/08	5/09
1998	10/09	10/05	318	216	66	4/23	4/22
1999	10/28	11/05	330	287	87	4/19	5/18
2000	10/15	11/21	373	279	75	4/07	4/18
Average	10/17	10/22	395	303	77	4/27	5/03

Table 2. Comparisons between open and canopy snow pillows at Onion Park on the Tenderfoot Creek Experimental Forest showing average melt-rates calculated over the period when both snow pillows were melting and melt-out dates for the period 1994 - 2000.

	Melt-Rates			Melt-Out Dates		
Water Year	Open mm/day	Canopy mm/day	Canopy as % Open	Open	Canopy	Days Difference
1994	10.6	4.7	44	5/24	6/03	10
1995	14.3	6.2	43	6/15	6/25	10
1996	18.3	9.1	50	6/07	6/12	5
1997	18.0	9.6	53	6/04	6/12	8
1998	10.2	4.3	42	5/24	6/02	9
1999	10.2	4.1	40	6/03	6/16	13
2000	9.4	4.2	45	5/27	6/07	11
Average	13.0	6.0	46	6/02	6/11	9

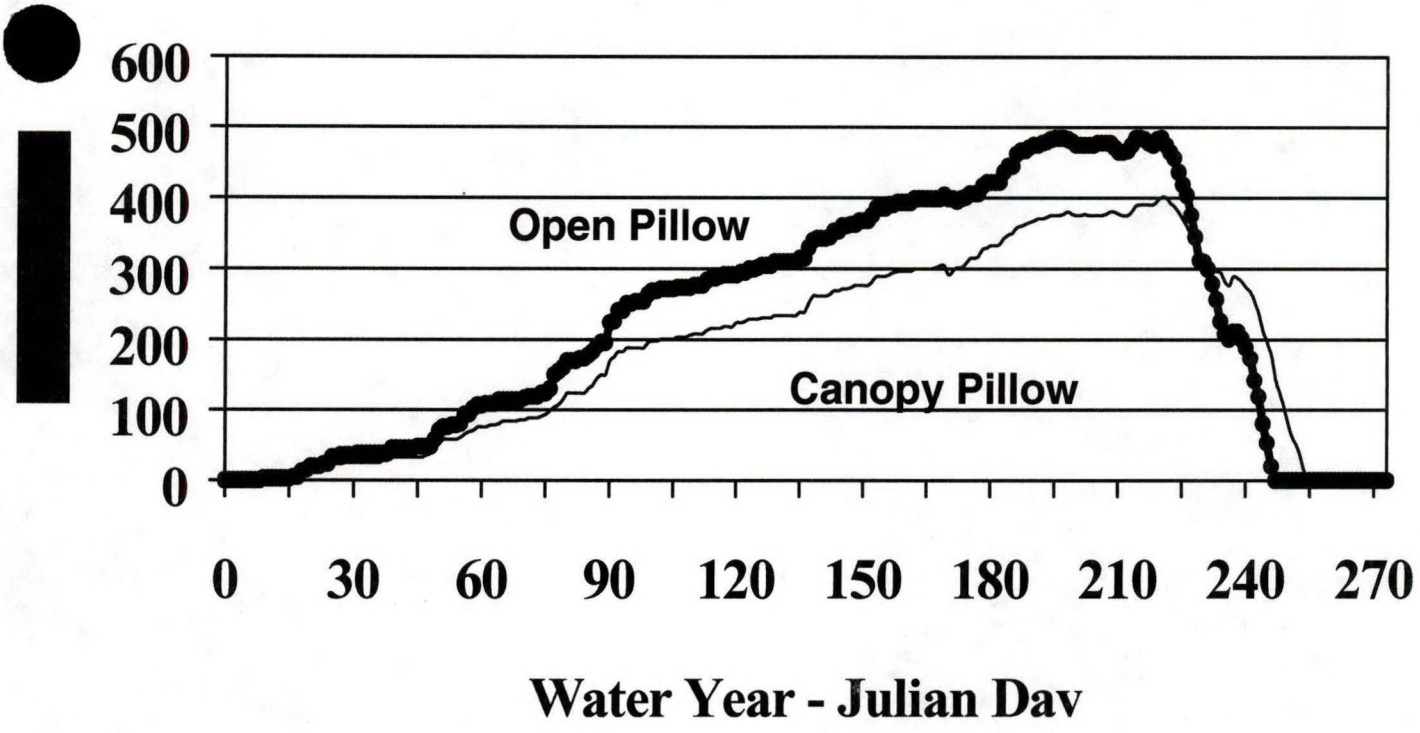


Figure 1. Daily snow water equivalent (SWE) at Onion Park on the Tenderfoot Creek Experimental Forest for open and canopy snow pillows for the 1997 water year (water year begins October 1).

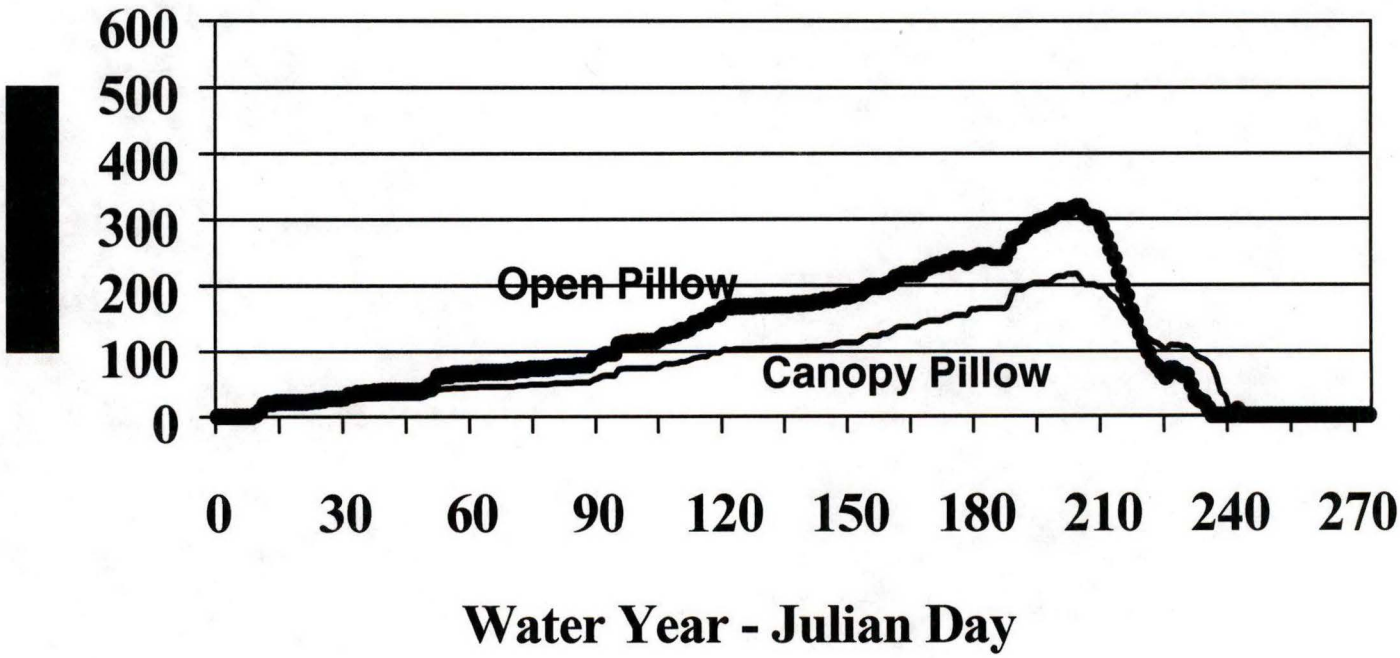


Figure 2. Daily snow water equivalent (SWE) at Onion Park on the Tenderfoot Creek Experimental Forest for open and canopy snow pillows for the 1998 water year (water year begins October 1).

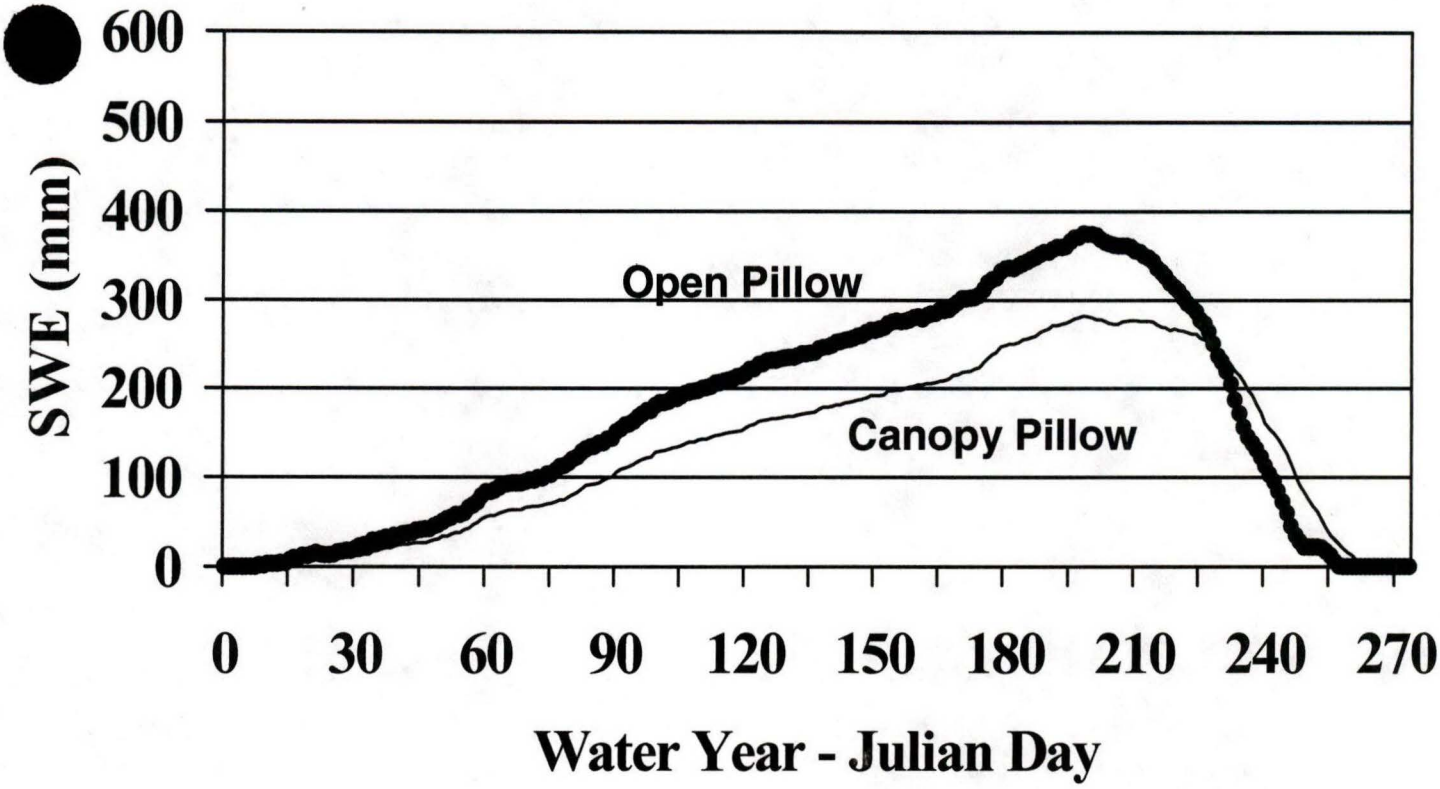


Figure 3. Average daily snow water equivalent (SWE) for the period 1994 - 2000 at Onion Park on the Tenderfoot Creek Experimental Forest for open and canopy snow pillows. Water year begins October 1.

DISCUSSION

There were measured differences in start date of snow accumulation, maximum SWE accumulation, average melt-rates and melt-out dates between the open and canopy pillows. The date of maximum accumulation varied by only a day between the open and canopy pillows, except in 1999 and 2000. From 1994 to 1998 the first melt-out period occurred immediately following the peak accumulation date, and, except for occasional minor snow accumulation periods, continued on a downward trend until melt-out. However, heavy snows came in late April and early May of 1999 and 2000 following the first melt period, and in 1999 the maximum accumulation on the canopy pillow exceeded the earlier accumulation prior to the first melt period. This second, higher peak accumulation prior to final melt-out occurred in 1999, only on the canopy pillow, due to lower melt-rates caused by shading from the forest canopy. In 2000, the pillow response was akin to 1999 except for a shorter time between peak accumulations. Both pillows responded similarly during these melt/accumulation periods.

The quantified differences from the open and canopy pillows are needed to model effects of canopy removal and crown development of subsequent regeneration on seasonal snowpacks. Replicated research harvest treatments were implemented in two sub-watersheds on the

Tenderfoot Creek Experimental Forest in 2000. Treatments included different crown removal levels and patterns of a two-aged harvesting system in nearly pure stands of lodgepole pine. Half of the research treatments will be prescribed burned in 2002. Changes in water yield and timing of snow melt and resulting runoff will be modeled using relationships developed between the open and canopy pillows along with other climatic and hydrologic data collected on the experimental forest. Predicted water yield will be compared to changes observed in the measured streamflow between two treatment sub-watersheds and adjacent control sub-watersheds that were not altered. The information from the two snow pillows at Onion Park on the Tenderfoot Creek Experimental Forest should be extractable to other Rocky Mountain forests that are predominately lodgepole pine.

Recent studies indicate that the majority of the accumulation difference between the canopy and open pillows is due to sublimation and not redistribution of snow (Schmidt and Troendle 1992, Pomeroy and Schmidt 1993, and Schmidt *et al.* 1998). Additional work needs to be done with precipitation throughfall and evapotranspiration to evaluate all the components affecting the hydrologic cycle in forested communities.

ACKNOWLEDGEMENTS

The NRCS Montana Snow Survey staff assisted with installation and operation of the snow pillows and provided water level recorders used for measurements. They have also assisted with the manual observations. The Rocky Mountain Research Station, U.S. Forest Service, U.S. Department of Agriculture provided the majority of funding for installation of these sites and the data collection.

LITERATURE CITED

Barrett, S. W. 1993. Fire History of Tenderfoot Creek Experimental Forest, Lewis and Clark National Forest. Internal report on file with U.S.D.A. Forest Service, Rocky Mountain Research Station, Montana State University, Bozeman, Montana.

Codd, A.R. 1959. The Photocanopyometer. In *Proceedings, Western Snow Conference*; April 21-23; Reno, NV. pp. 17-23.

Farnes, P.E. and R. K. Hartman. 1989. Estimating the Effects of Wildfire on Water Supplies in the Northern Rocky Mountains. In *Proceedings, 57th Western Snow Conference,* Fort Collins, Colorado, April 18-20. pp. 90-99.

Farnes, P. E., W. W. McCaughey and K. J. Hansen. 1995. Hydrologic and Geologic Characterization of Tenderfoot Creek Experimental Forest, Montana. Final Report RJVA-INT-92734. Department of Earth Sciences, Montana State University, Bozeman, MT. 63 p.

Farnes, P. E., W. W. McCaughey and K. J. Hansen. 1999. Flumes, Historic Water Yield andClimatological Data for Tenderfoot Creek Experimental Forest, Montana; Final Report RJVA-INT-96071. Department of Earth Sciences, Montana State University, Bozeman, MT. 37 p.

Farnes, P. E., W. W. McCaughey and K. J. Hansen. 2001. Role of Fire in Determining Annual Water Yield in Mountain Watersheds. In *Chapter 11 After the Fire: Ecology of Change in Yellowstone National Park.* Edited by Linda Wallace, Yale University Press. (In press).

Gary, H. L. and C. A. Troendle. 1982. Snow Accumulation and Melt Under Various Stand Densities in Lodgepole Pine in Wyoming and Colorado. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Research Note RM-417. Washington, D.C.: Government Printing Office, pp. 1-7.

Moore, C. A. and W. W. McCaughey. 1997. Snow Accumulation Under Various Forest Stand Densities at Tenderfoot Creek Experimental Forest, Montana, USA. In *Proceedings 65th Annual Western Snow Conference*, Banff, Alberta, Canada, May 4-8, pp. 42-51.

Pomeroy, J.W. and R.A. Schmidt. 1993. The Use of Fractal Geometry in Modeling Intercepted Snow Accumulation and Sublimation. In *Proceedings 61th Annual Western Snow Conference*, Quebec City, Canada, June 8-10, pp. 1-10.

Schmidt R.A. and C.A. Troendle. 1992. Sublimation of Intercepted Snow as a Global Source of Water Vapor. In *Proceedings 60th Annual Western Snow Conference*, Jackson, Wyoming, April 14-16, pp. 1-9.

Schmidt, R.A., C. A.Troendle, and J.R. Meiman. 1998. Sublimation of Snowpacks in Subalpine Conifer Forests. Can. J. For. Res. 28: 501-513.

Skidmore, P.B., K. J. Hansen and W. Quimby. 1994. Snow Accumulation and Ablation Under Fire-Altered Lodgepole Pine Forest Canopies. In *Proceedings, 62nd Western Snow Conference*, Santa Fe, New Mexico, April 18-21, pp. 43-55.